7th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 14–18, 1999

Low flicker noise GaN/AlGaN heterostructure field effect transistors with submicrometer channel

S. Morozov, A. Balandin†, S. Cai†, R. Li†, Yu. Dubrovskii, K. L. Wang†, G. Wijeratne† and C. R. Viswanathan†
Institute of Microelectronics Technology RAS,
142432 Chernogolovka, Russia
† Electrical Engineering Department, University of California-Los Angeles
Los Angeles, California 90095-1594

1 Introduction

Recently, wide bandgap compound semiconductors demonstrated potential for high frequency and high power density device applications. These materials offer several inherent advantages, such as higher breakdown voltage, higher thermal conductivity, comparable carrier mobility, and high saturation velocity. GaN is among those which show a great promise for microwave applications.

Development of high performance microwave technology requires detailed knowledge of the noise behavior of the devices. Particularly, it is important to know the value of flicker noise, e.g. $1/f$ noise, since this type of noise is the limiting figure for all kinds of HEMTs and MOSFETs.

In this paper we report investigation of $1/f$ flicker noise in GaN/$Al_{0.15}Ga_{0.85}N$ doped channel heterostructure field effect transistors (referred as GaN HFET).

2 Device structure and measurements

The layered structure was fabricated by MBE on a sapphire substrate. A 1.0 μm thick i-GaN buffer layer was followed by 50 nm thick n-GaN layer with the doping level of 5×10^{17} cm^{-3}, and 3 nm thick i-$Al_{0.15}Ga_{0.85}N$ undoped spacer layer. On top, there was 30 nm thick $n - Al_{0.15}Ga_{0.85}N$ layer with the doping level of 2×10^{18} cm^{-3}. The barrier and channel doping resulted in a sheet electron concentration of about 1.6×10^{13} cm^{-2}. Electron Hall mobility was determined to be 460 cm^2/Vs at room temperature.

Devices selected for this study had a fixed gate length $L_G = 0.25$ μm. A device with $L_{DS} = 3$ μm had the drain current $I_{DS} = 0.55$ A/mm at the gate bias $V_{GS} = -3.0$ V. The maximum transconductence (for negative gate biases) was $g_m = 102$ mS/mm (at $V_{GS} = -5$ V). A device with $L_{DS} = 2$ μm had the maximum transconductence (for negative gate biases) $g_m = 133$ mS/mm at $V_{GS} = -3$ V ($L_G = 0.25$ μm).

We have examined a large number of devices with the gate width $W = 2 \times 40$ μm, and four different source — drain separation distances $L_{SD} = 2$; 3; 4; and 5 μm. All examined devices were made on the same wafer. For these devices we obtained experimental dependence of the equivalent input referred noise power spectrum on frequency, gate and drain voltages. The measurements were carried out for both the linear region of the device operation corresponding to low drain-source voltage, V_{DS}, and the onset of the saturation region of operation (subsaturation) corresponding to $V_{DS} = 5$ V.

The slope ν of the $1/f^{\nu}$ dependence in all spectra is very close to 1, although varies for

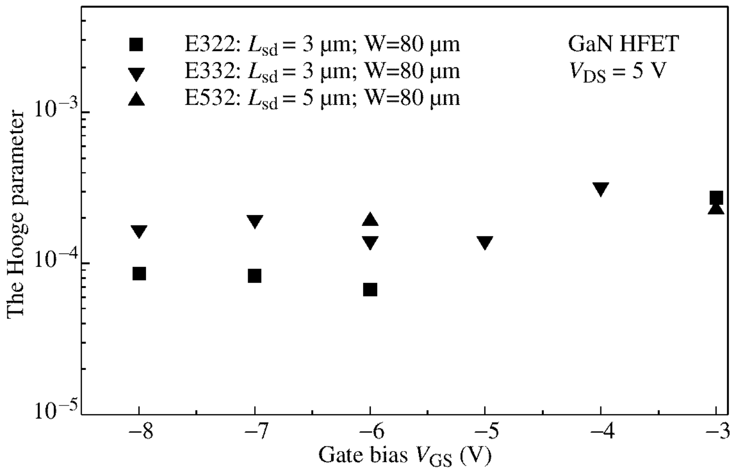

Fig. 1. Hooge parameter α_H as a function of the gate bias. The results are shown for three devices biased at $V_{DS} = 5$ V. The gate dimensions are 0.25 μm $\times$ 80 μm.

different devices and gate bias values. We did not observe any clear trace of the generation-recombination $(g - r)$ bulges in the noise spectra.

The equivalent input-referred noise spectral density was obtained from the drain current noise spectral density using the regular relation

$$S_{V_{eq}} = \frac{S_{I_D}}{g_m^2}, \tag{1}$$

where $S_{V_{eq}}$ is the equivalent input-referred noise spectral density, S_{I_D} is the drain current noise spectral density, and g_m is the transconductance of the device.

At relatively small absolute values of the gate bias $|V_{GS}|$, the noise spectral density S_V is gate bias dependent, and decreasing with a higher negative bias. At high absolute values of the gate bias when the channel is almost pinched off, the noise density is about the same for different values of V_{GS}. This type of behavior was characteristic for all examined transistors.

In order to have quantitative characteristic of the overall noise in the device, we use the Hooge parameter α_H [ ] introduced via the equation

$$\frac{S_{I_D}}{I_D^2} = \frac{\alpha_H}{Nf}, \tag{2}$$

where f is the frequency, N is the total number of carriers under the gate calculated from the drain-source current at which the noise was measured. The number of carriers in homogeneous samples can be expressed as

$$N = \frac{L^2}{Re\mu}. \tag{3}$$

Here μ is the mobility in the conducting channel, R is the resistance between two device terminals, and L is the channel length. Two quantities (R and μ) in Eq. (3) are determined

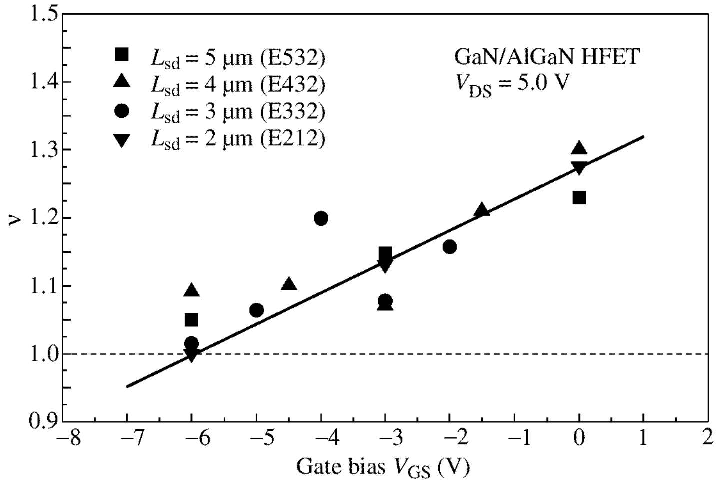

Fig. 2. Dependence of the exponent ν of the $1/f^{\nu}$ noise power density on the gate bias. The results are shown for four devices with different L_{DS}. All four devices are biased at $V_{DS} = 5$ V. The exponent ν approaches 1 with more negative bias.

experimentally. The resistance is found at a given V_{DS} during the noise measurements, while the mobility is determined for the layered structure using the Hall measurements. The gate leakage current for the devices was small (less then 1%), and hence its effect on their noise performance was neglected. Finally, the Hooge parameter was calculated using Eqs. (1)–(3) for different devices and bias points. The results for $V_{DS} = 5$ V are given in Fig. 1. Despite some variations of the of the α_H parameter values, they are all close to 10^4. It is also seen that α_H almost does not depend on the gate bias. For all examined values of L_{DS}, the Hooge parameter was in the same range and did not show any clear trend. Based on this, we concluded that the source — distance separation does not strongly affect low-frequency noise performance of GaN HFETs.

One should note that the Hooge parameter α_H in our analysis was used as a figure of merit for purpose of comparison with other published results, and was not intended to suggest the mobility fluctuation model and not carrier density fluctuation noise model for our devices [2].

In an attempt to clarify the origin of the low-frequency noise in our devices, we extracted the exponent ν of the $1/f^{\nu}$ noise power density for all examined devices and studied its gate bias dependence. The ν vs. V_{GS} dependences are shown in Fig. 2 for four devices with different L_{DS}. All four devices are biased at $V_{DS} = 5$ V. One can see that ν is in the range of $1.0 < \nu < 1.3$ and decreases with increasing (more negative) gate bias. Such a dependence of the magnitude of the $1/f^{\nu}$ noise spectral density can be most easily interpreted in terms of the modified carrier density fluctuation model [3] which is an extension of the well-established McWhorter formalism. The modified carrier-density fluctuation model explains the liner dependence of the exponent ν on the gate bias by the nonuniformity of the trap distribution. The argument is that trap density across the band gap varies with energy, and the band bending with increasing gate voltage will change the number of effective traps, and thus the time constants contributing to $1/f^{\nu}$ noise. Since the quality of GaN/AlGaN heterojunctions remains rather poor, we expect a lot of imperfections (traps) nonuniformly distributed both in energy and space. Due to this reason, the above interpretation of the pronounced ν dependence on the gate bias seems very realistic.

Conclusions

We have carried out a detailed investigation of the low-frequency noise characteristics of GaN HFETs grown on sapphire substrate. Our results indicate that the average value of the Hooge parameter α_H of GaN HFETs is on the order of 10^{-4}. This low value of the $1/f$ noise is comparable to the noise level in conventional GaAs FETs. The latter indicates possibility of the use of microwave GaN HFETs in communication systems, particularly those requiring high power density and high temperature operation. The presented results also allow to model the noise response of the devices for different gate and drain biases and device geometrical dimensions.

This work was, in part, supported by the DoD MURI-ARO program on "Low-Power/Low-Noise Electronic Technology for Mobile Communications" and by CRDF-RFBR (Grant RP1-220).

References

[1] F. N. Hooge, T. G. M. Kleinpenning and L. K. J. Vandamme, *Rep. Prog. Phys.* **44**, 479 (1981).
[2] L. K. J. Vandamme, *Solid State Electron.* **23**, 317 (1980).
[3] Z. Celik-Butler and T. Y. Hsiang, *Solid State Electron.* **30**, 419 (1987).